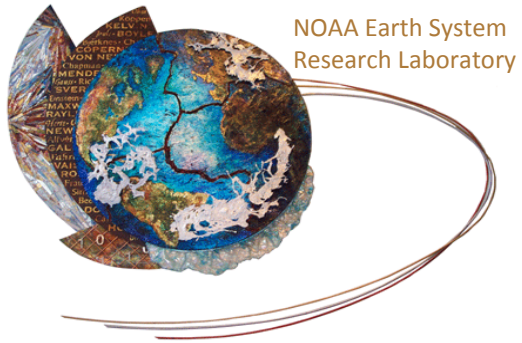

Statistical post-processing using reforecasts to improve medium-range renewable energy forecasts

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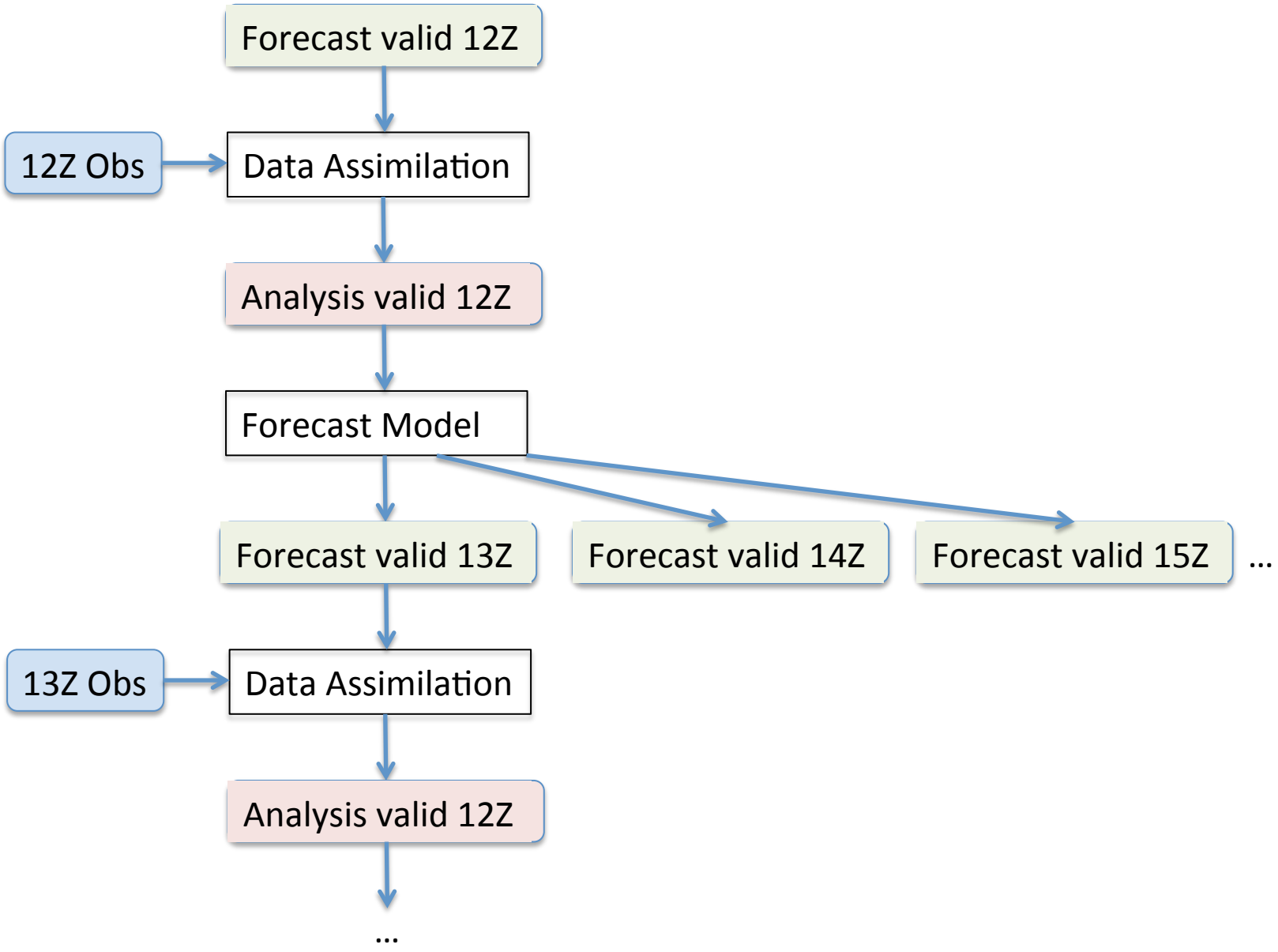
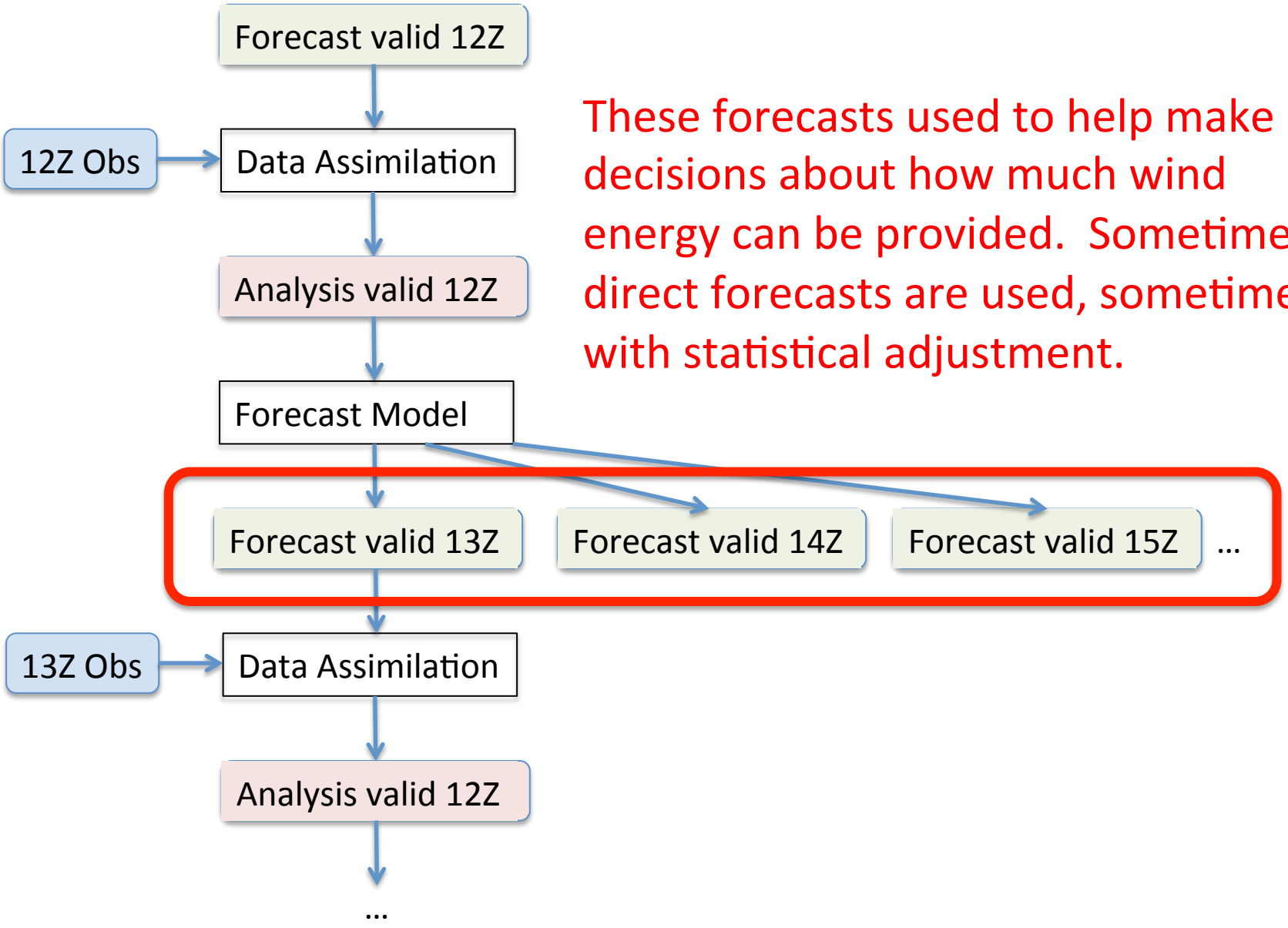
Wind energy decisions based on weather forecasts

- Most consequential decisions are "unit commitments" (~ 1 day) and then updates using very short-range forecasts to adjust.
- Less consequential O&M decisions might be based on longer-lead forecasts.
- Questions:
  - Can we improve long-lead forecasts to support, say, maintenance decisions?
  - Can we make, say, 2-day forecasts as well as we make current 1-day forecasts so that unit commitment decisions might be made further in advance?
  - What new data sets and approaches might be tried to improve these longer-lead forecasts?

Current assimilation/forecast process

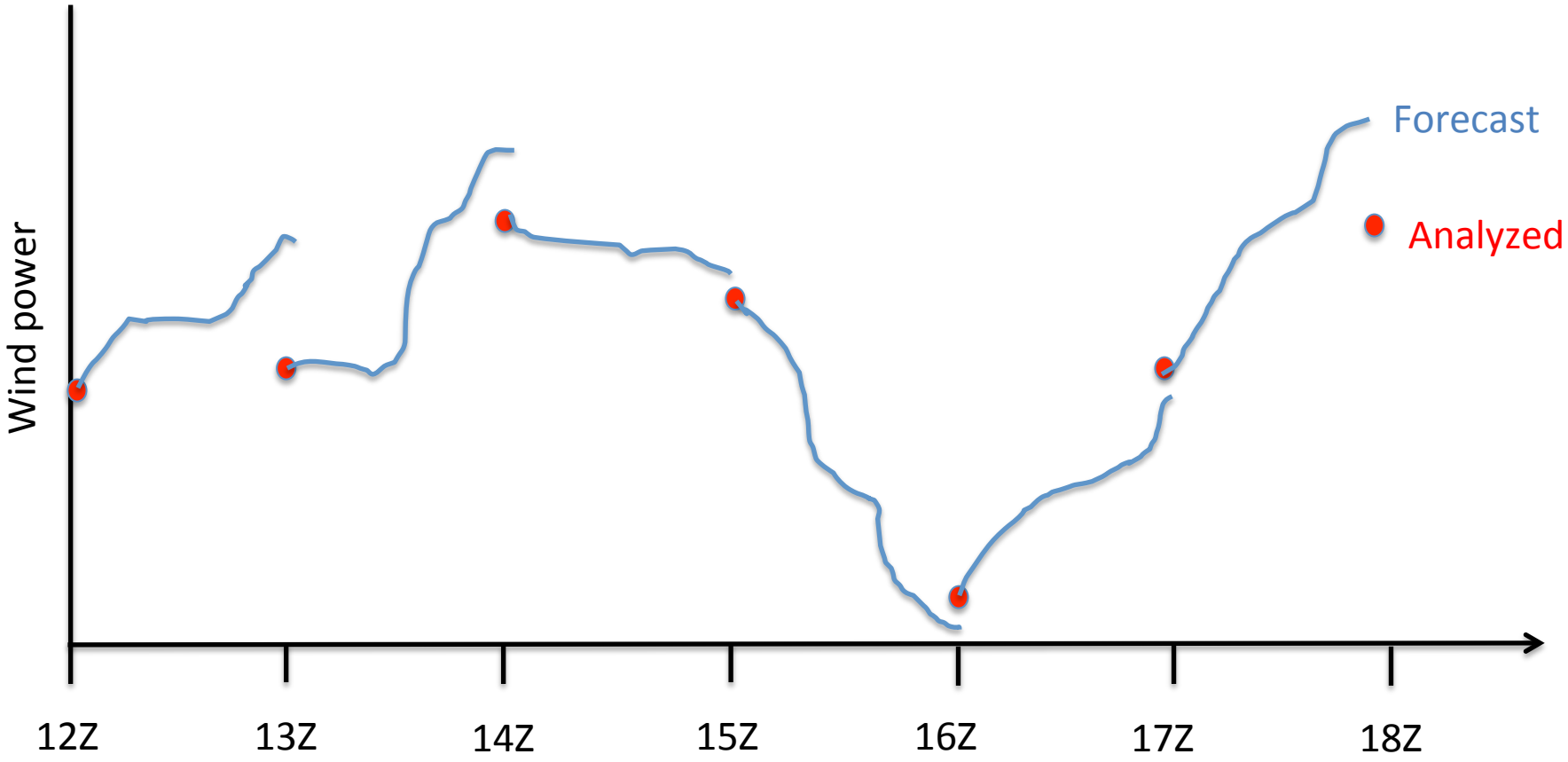


Current assimilation/forecast process

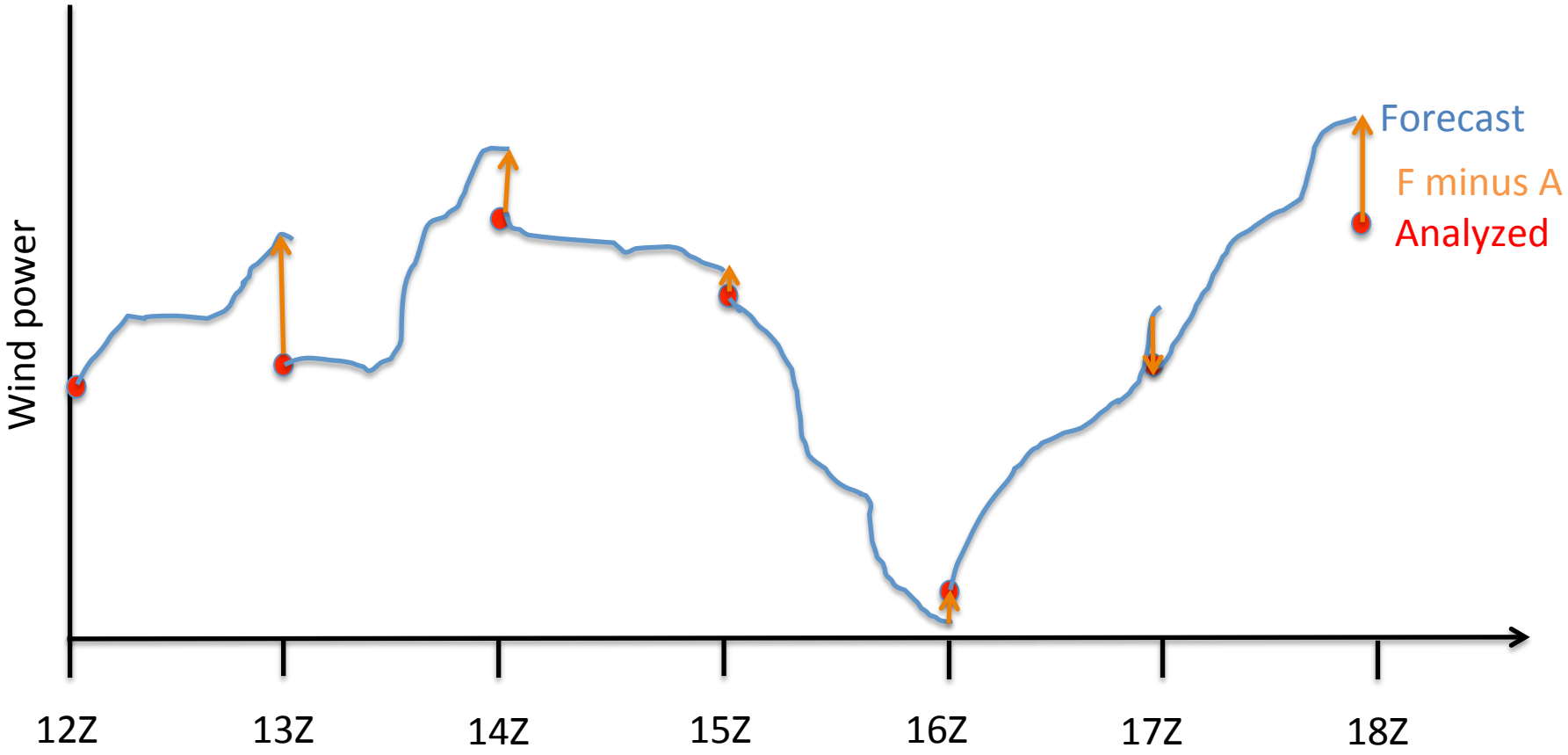


These forecasts used to help make decisions about how much wind energy can be provided. Sometimes direct forecasts are used, sometimes with statistical adjustment.

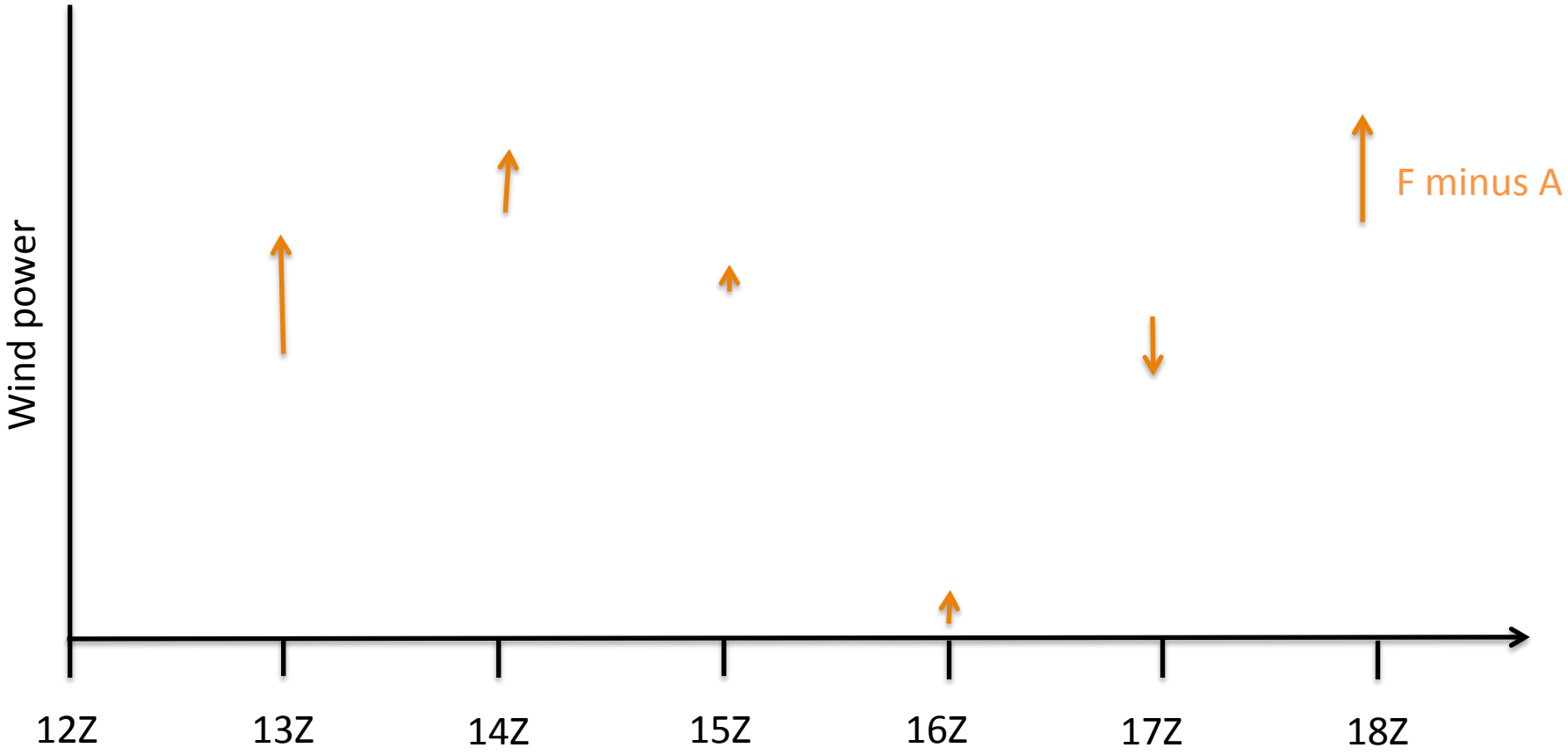
Challenges in directly using forecast guidance



Challenges in directly using forecast guidance

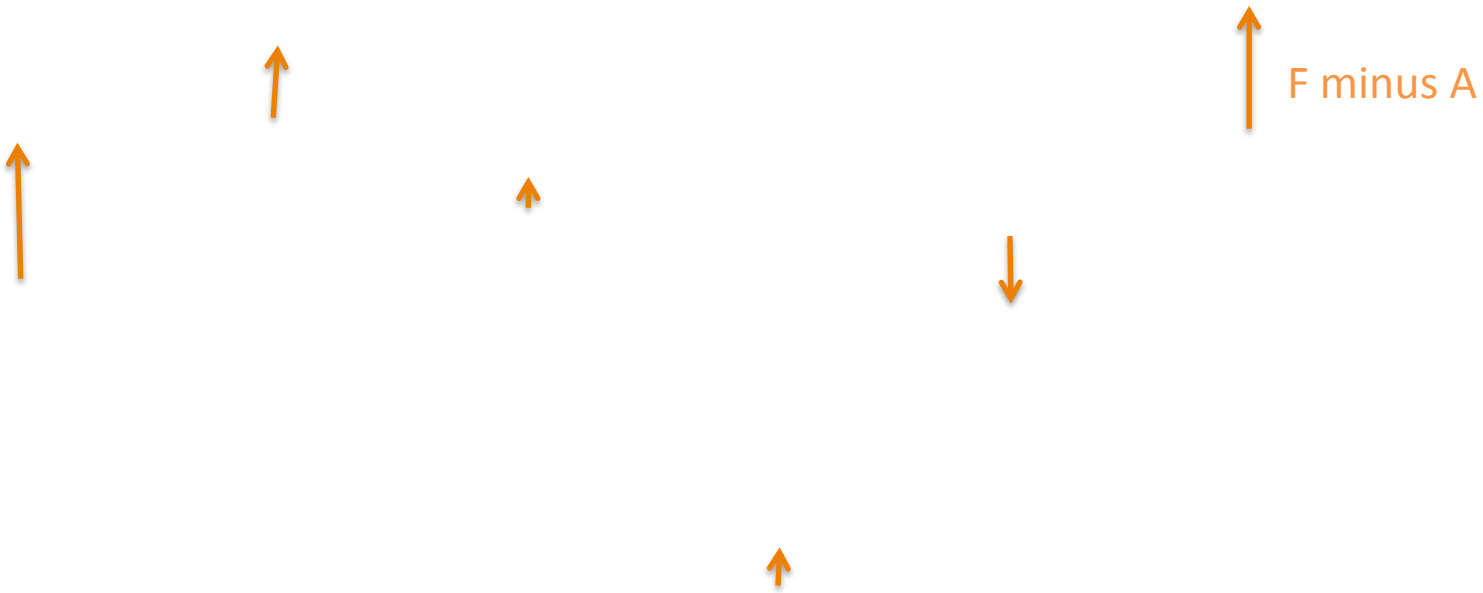


Challenges in directly using forecast guidance

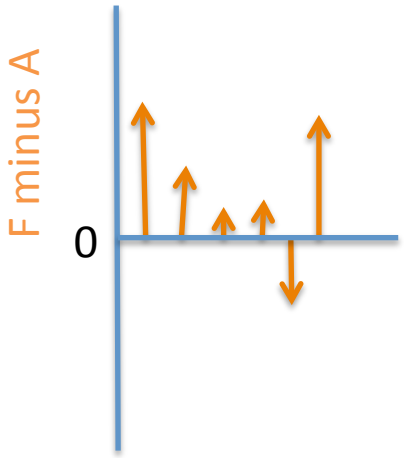


Errors are some mix of systematic errors due to the forecast model deficiencies and random errors due to the chaotic growth from small analysis errors.

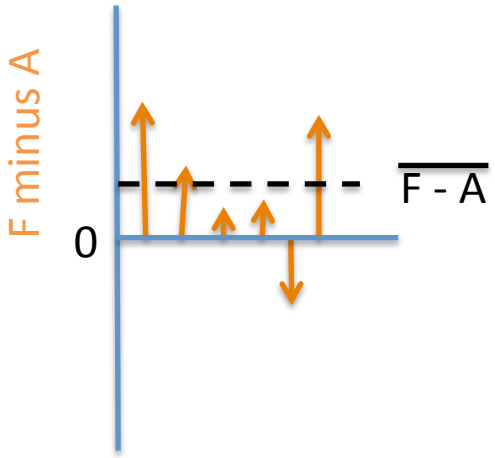
Challenges in directly using forecast guidance



Challenges in directly using forecast guidance

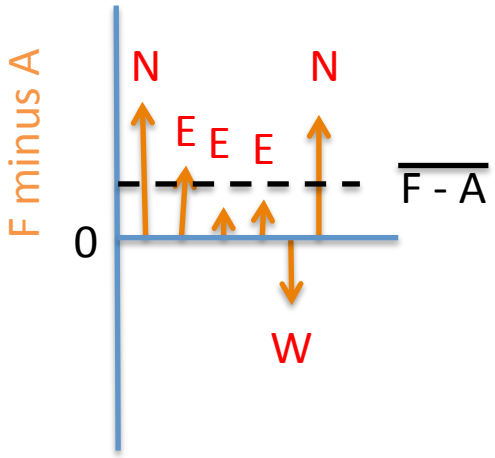


Challenges in directly using forecast guidance



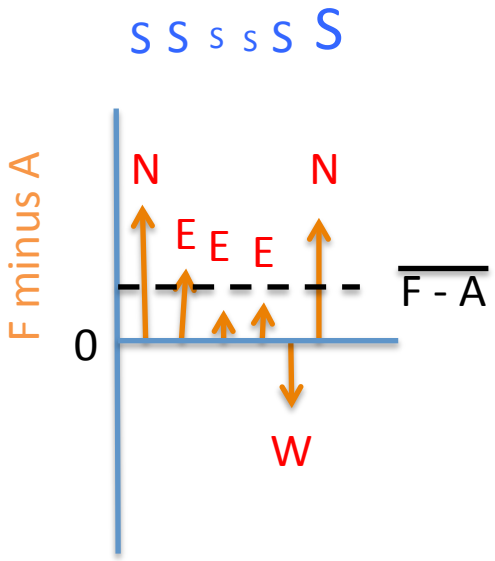
an overall bias correction should result in a modest improvement in the forecasts

Challenges in directly using forecast guidance



What if we had additional information such as the wind direction? Then perhaps a more sophisticated statistical correction could be attempted.

Challenges in directly using forecast guidance



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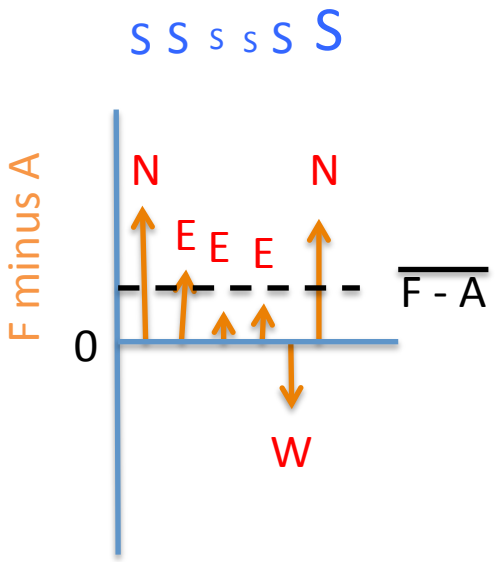
What if we had further additional information such as static stability "S" ?

Challenges in directly using forecast guidance



What if we had additional information such as the wind direction? Then perhaps a more sophisticated statistical correction could be attempted.

What if we had further additional information such as static stability "S" ?

The more additional predictors you may wish to include in some statistical correction model, the longer the time series of forecasts and observations you are going to need.

Reforecasts (hindcasts)

- Numerical simulations of the past weather (or climate) using the same forecast model and assimilation system that (ideally) is used operationally.
  - Very common with climate, still uncommon with weather models.
- Reforecasts may be initialized from reanalyses, but reforecasts ≠ reanalyses

GEFS reforecast v2 details

- Seeks to mimic GEFS (NCEP Global Ensemble Forecast System) operational configuration as of February 2012.
- Each 00Z, 11-member forecast, 1 control + 10 perturbed.
- Reforecasts produced every day, for 1984120100 to current (actually, working on finishing late 2012 now).
- CFSR (NCEP's Climate Forecast System Reanalysis) initial conditions (3D-Var) + ETR perturbations (cycled with 10 perturbed members). After ~ 22 May 2012, initial conditions from hybrid EnKF/3D-Var.
- Resolution: T254L42 to day 8, T190L42 from days 7.5 to day 16.
- Fast data archive at ESRL of 99 variables, 28 of which stored at original ~1/2-degree resolution during week 1. All stored at 1 degree. Also: mean and spread to be stored.
- Full archive at DOE/Lawrence Berkeley Lab, where data set was created under DOE grant.

Status

- 00Z reforecasts 1985-late 2012 completed and publicly available.
- Within a month or two, we will be pulling real-time GEFS data over from NCEP and putting it in our archive.
- Web sites are open to you now:
  - NOAA/ESRL site: fast access, limited data (99 fields).
  - US Department of Energy: slow access, but full data set
- Soon: experimental probabilistic precipitation forecast graphics in real time.

Data to be readily available from ESRL

Table 1: Reforecast variables available for selected mandatory and other vertical levels. Φ indicates geopotential height, and an X indicates that this variable is available from the reforecast data set at 1-degree resolution; a Y indicates that the variable is available at the native ~0.5 degree resolution. AGL indicates "above ground level."

Vertical Level	U	V	T	Φ	q	Wind Power
10 hPa	X	X	X	X		
50 hPa	X	X	X	X		
100 hPa	X	X	X	X		
200 hPa	X	X	X	X		
250 hPa	X	X	X	X		
300 hPa	X	X	X	X	X	
500 hPa	X	X	X	X	X	
700 hPa	X	X	X	X	X	
850 hPa	X	X	X	X	X	
925 hPa	X	X	X	X	X	
1000 hPa	X	X	X	X	X	
$\sigma \cong 0.996$	X	X		X		
$\sigma \cong 0.987$	X	X		X		
$\sigma \cong 0.977$	X	X		X		
$\sigma \cong 0.965$	X	X		X		
80m AGL	X,Y	X,Y				X,Y

Also: hurricane track files

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500 hPa	X	X	X	X	X	
700 hPa	X	X	X	X	X	
850 hPa	X	X	X	X	X	
925 hPa	X	X	X	X	X	
1000 hPa	X	X	X	X	X	
σ ≅ 0.996	X	X		X		
σ ≅ 0.987	X	X		X		
σ ≅ 0.977	X	X		X		
σ ≅ 0.965	X	X		X		
80m AGL	X,Y	X,Y				X,Y

useful for wind energy?

Also: hurricane track files

Data to be readily available from ESRL at native resolution (~0.5 degree in week 1, ~0.7 degree in week 2)

- Total Accumulated Precipitation
- U-Component of Wind at 10 meters
- U-Component of Wind at 80 meters
- Convective Available Potential Energy
- Surface Downward Long-Wave Radiation Flux
- Surface Upward Long-Wave Radiation Flux
- Ground Heat Flux
- Surface Sensible Heat Net Flux
- Precipitable Water
- Specific Humidity at 2 meters
- Skin Temperature
- Minimum Temperature
- Upward Long-Wave Radiation Flux
- Water Equivalent of Accumulated Snow Depth
- Temperature at 2 meters
- V-Component of Wind at 10 meters
- V-Component of Wind at 80 meters
- Convective Inhibition
- Surface Downward Short-Wave Radiation Flux
- Surface Upward Short-Wave Radiation Flux
- Surface Latent Heat Net Flux
- Mean Sea Level Pressure
- Volumetric Soil Moisture Content
- Total Column-Integrated Condensate
- Maximum Temperature
- Soil Temperature (0-10 cm below surface)
- Water Runoff
- Wind Mixing Energy

Data to be readily available from ESRL at native resolution (~0.5 degree in week 1, ~0.7 degree in week 2)

- Total Accumulated Precipitation
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- Ground Heat Flux
- Surface Sensible Heat Net Flux
- Precipitable Water
- Specific Humidity at 2 meters
- Skin Temperature
- Minimum Temperature
- Upward Long-Wave Radiation Flux
- Water Equivalent of Accumulated Snow Depth
- Temperature at 2 meters
- V-Component of Wind at 10 meters
- V-Component of Wind at 80 meters
- Convective Inhibition
- Surface Downward Short-Wave Radiation Flux
- Surface Upward Short-Wave Radiation Flux
- Surface Latent Heat Net Flux
- Mean Sea Level Pressure
- Volumetric Soil Moisture Content
- Total Column-Integrated Condensate
- Maximum Temperature
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- Water Runoff
- Wind Mixing Energy

- of particular relevance for hydro, wind, and solar renewable-energy forecasting

esrl.noaa.gov/psd/forecasts/reforecast2/download.html

Select Desired Variables and Associated Levels:

Single Level (1°x1°) | Pressure Levels (1°x1°) | Hybrid Levels (1°x1°) | Single Level (Gaussian ~.5°)

- Total Accumulated Precipitation
- U-Component of Wind at 10 meters
- U-Component of Wind at 80 meters
- Convective Available Potential Energy
- Surface Downward Long-Wave Radiation Flux
- Surface Upward Long-Wave Radiation Flux
- Ground Heat Flux
- Surface Sensible Heat Net Flux
- Surface Pressure
- Volumetric Soil Moisture Content
- Total Cloud Cover
- Skin Temperature
- Minimum Temperature
- Upward Long-Wave Radiation Flux
- Water Equivalent of Accumulated Snow Depth
- Vertical Velocity at 850 hPa Surface
- Pressure on 2 PVU Surface
- V-Component of Wind on 2 PVU Surface
- Temperature at 2 meters
- V-Component of Wind at 10 meters
- V-Component of Wind at 80 meters
- Convective Inhibition
- Surface Downward Short-Wave Radiation Flux
- Surface Upward Short-Wave Radiation Flux
- Surface Latent Heat Net Flux
- Mean Sea Level Pressure
- Precipitable Water
- Specific Humidity at 2 meters
- Total Column-Integrated Condensate
- Maximum Temperature
- Soil Temperature (0-10 cm below surface)
- Water Runoff
- Wind Mixing Energy
- Temperature on 2 PVU Surface
- U-Component of Wind on 2 PVU Surface
- Potential Vorticity on 320 K Isentrope

Select Desired Dates (Available from Dec 1 1984 to Dec 31 2010):

From: **To:**

- Download all the forecasts within the chosen time period. Help
- Download forecasts within the month-days range for the chosen years. Help

Select Desired Forecast Hour(s):

High Resolution: (Select All or Clear)

0	3	6	9	12	15	18	21	24	27
30	33	36	39	42	45	48	51	54	57
60	63	66	69	72	78	84	90	96	102
108	114	120	126	132	138	144	150	156	162
168	174	180	186	192					

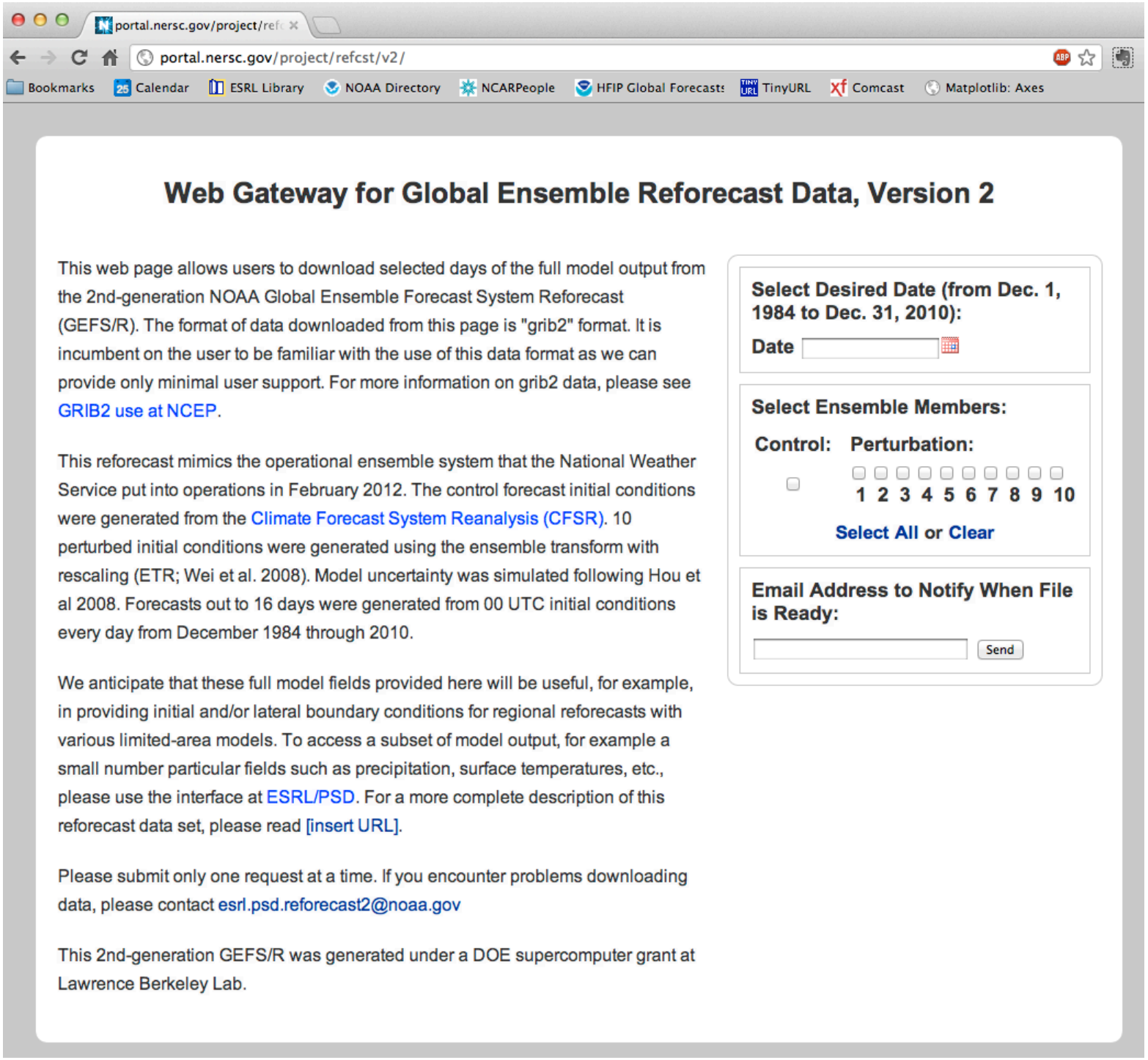
Low Resolution: (Select All or Clear)

186	192	198	204	210	216	222	228	234	240
246	252	258	264	270	276	282	288	294	300
306	312	318	324	330	336	342	348	354	360
366	372	378	384						

Your point-and-click gateway to the reforecast archive.

Produces netCDF files.

Also: direct ftp access to allow you to read the raw grib files.

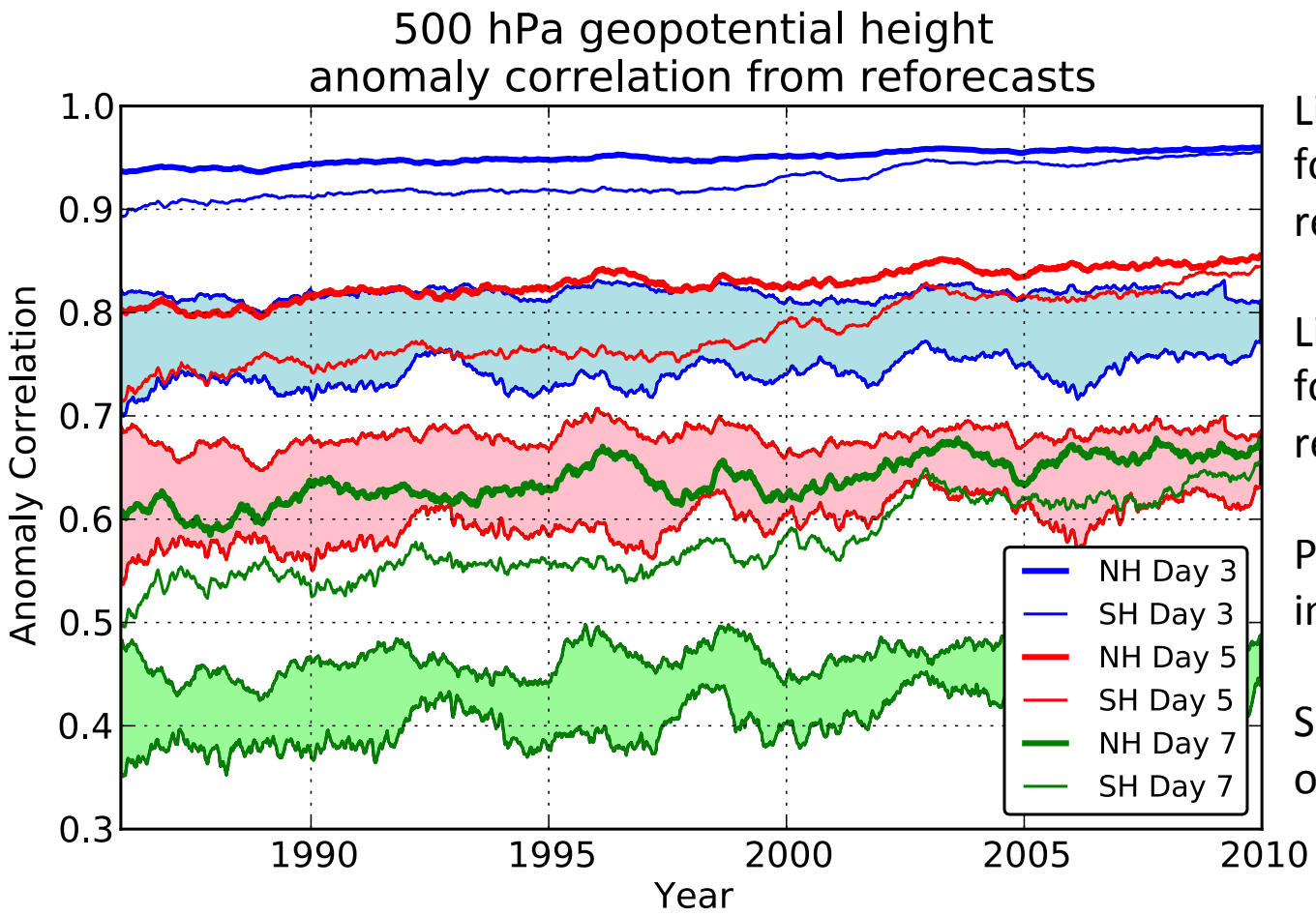


This DOE site will be ready for access to tape storage of full data (slower).

Use this to access full model state.

Skill of raw reforecasts (no post-processing)

500 hPa Z anomaly correlation
(from deterministic control)



Lines w/o filled colors for second–generation reforecast (2012, T254)

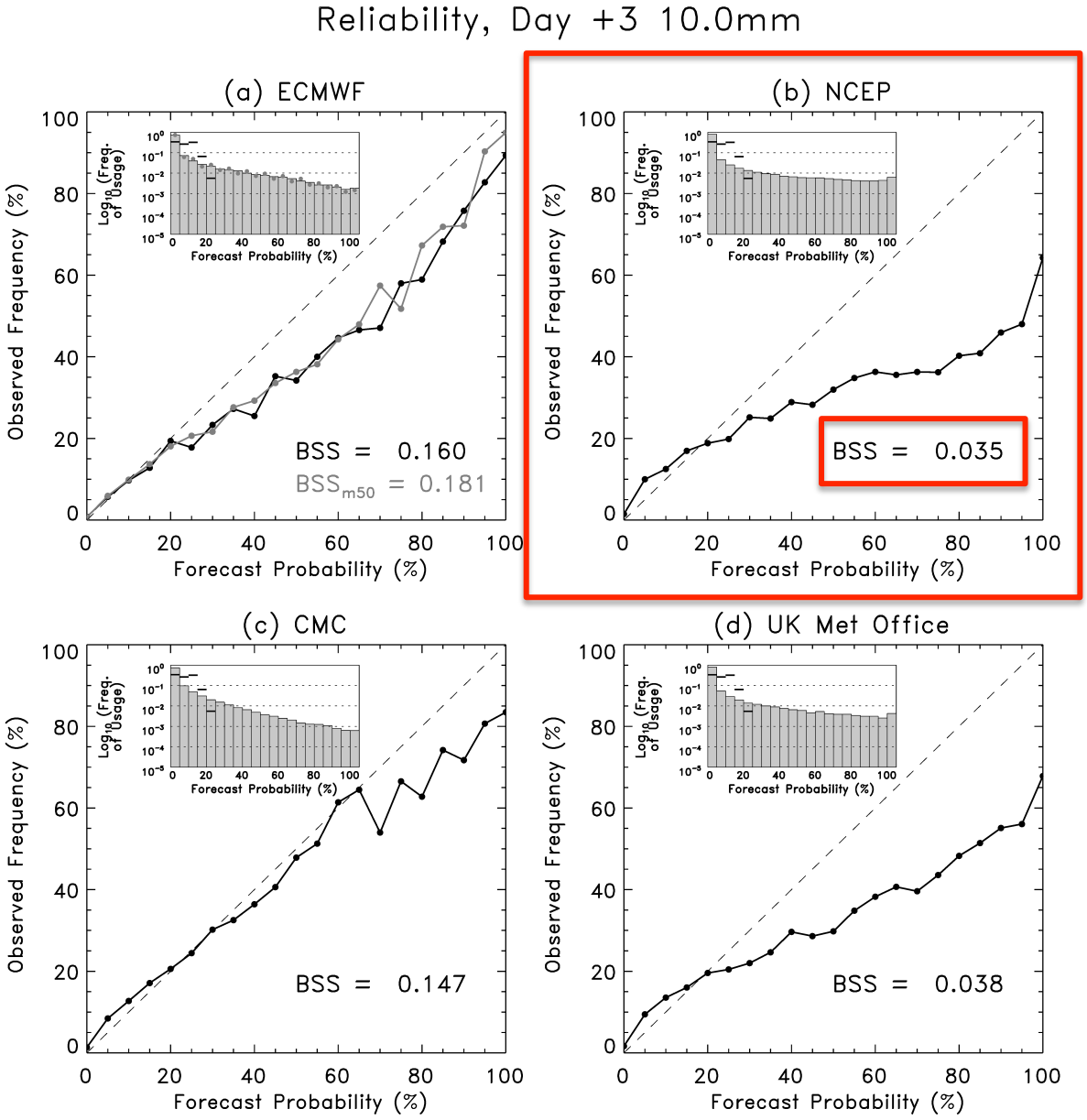
Lines with filled colors for first-generation reforecast (1998, T62).

Perhaps a 1.5-2.5 day improvement.

Some change in skill over period of reforecast.

Statistical post-processing using reforecasts

Statistical post-processing of precipitation forecasts



Probabilities directly estimated from ensemble prediction systems are often unreliable.

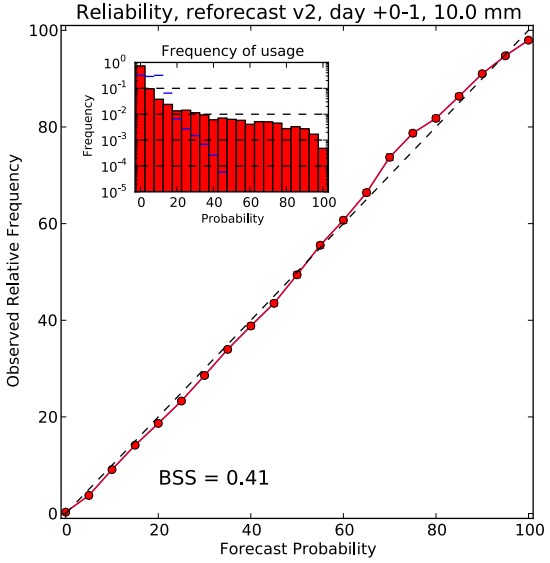
This is data from Jul-Oct 2010, when the GEFS was T190.

Can we statistically post-process the current GEFS using reforecasts and improve reliability and skill?

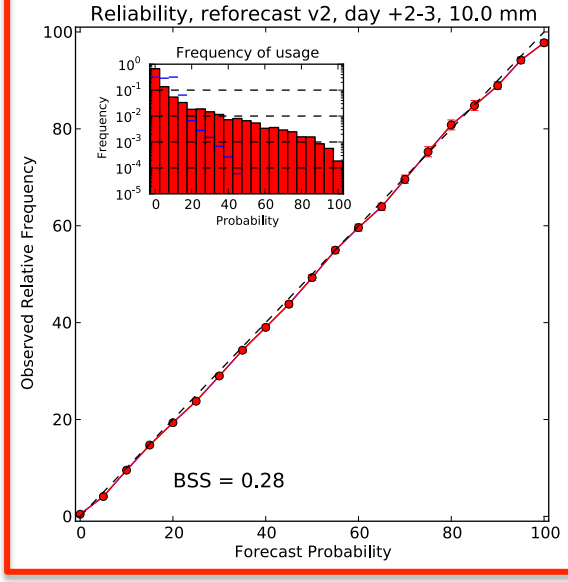
Reliability, > 10 mm precipitation 24 h^{-1}

Version 2 (2012 GEFS)

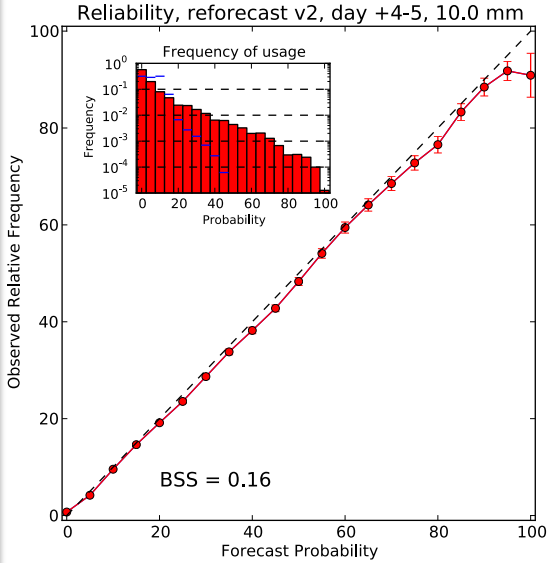
Day +0-1



Day +2-3

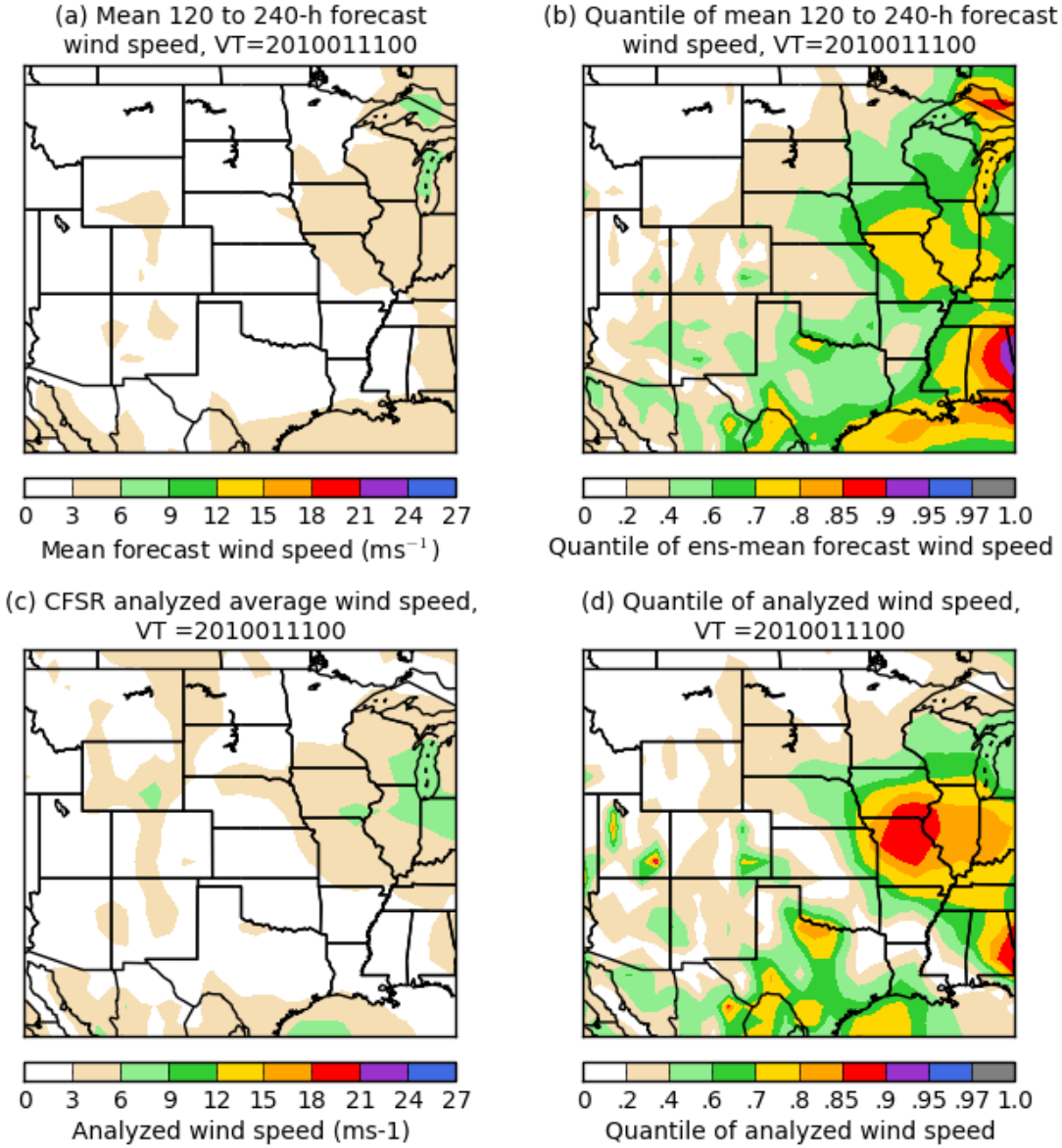


Day +4-5



Almost perfect reliability, greatly improved skill with a very simple statistical post-processing algorithm leveraging the long reforecast data set.

Application to wind energy: what if there's no time series of observed data?



Say you don't have observational or analysis data widely available for statistical post-processing. How can you leverage reforecasts to tell you whether or not today's weather is unusual?

Here's an example quantifying how unusual the forecast wind speed is relative to past model forecasts of wind speed for a similar time of the year.

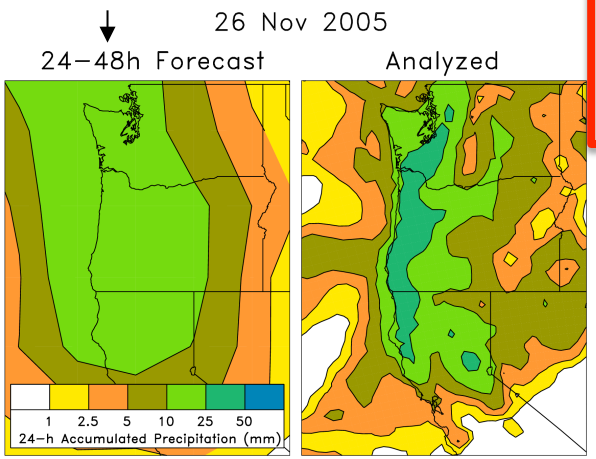
This might be useful for making decisions for wind energy, for example.

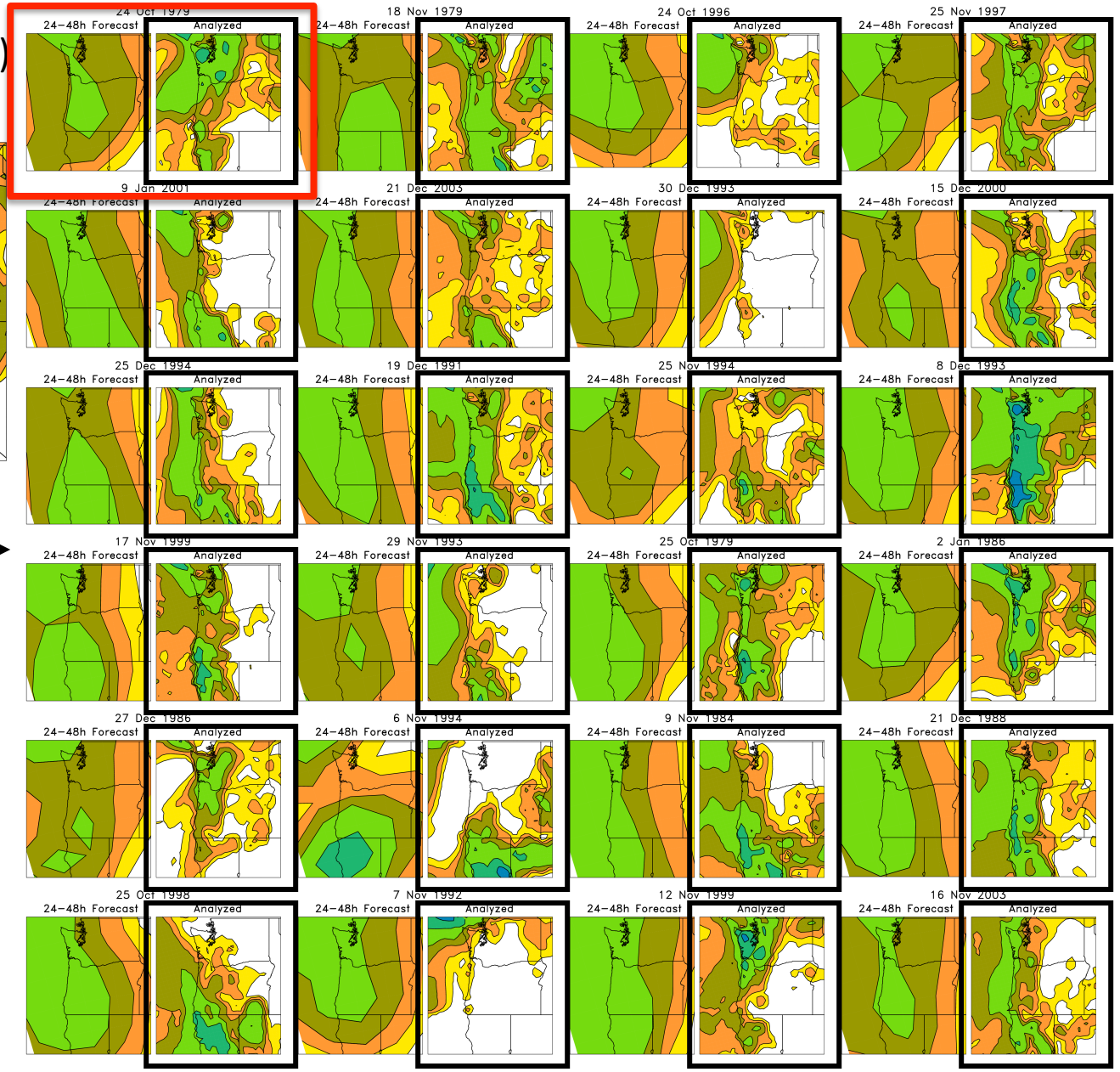
Conclusions

- Reforecast data set has been created for current operational NCEP GEFS.
- Reforecast data and real-time forecasts available now, or will be soon.
- May be useful for statistical calibration and developing improved products for renewable-energy forecasts.

An example of a statistical correction technique using those reforecasts

Today's forecast (& observed)



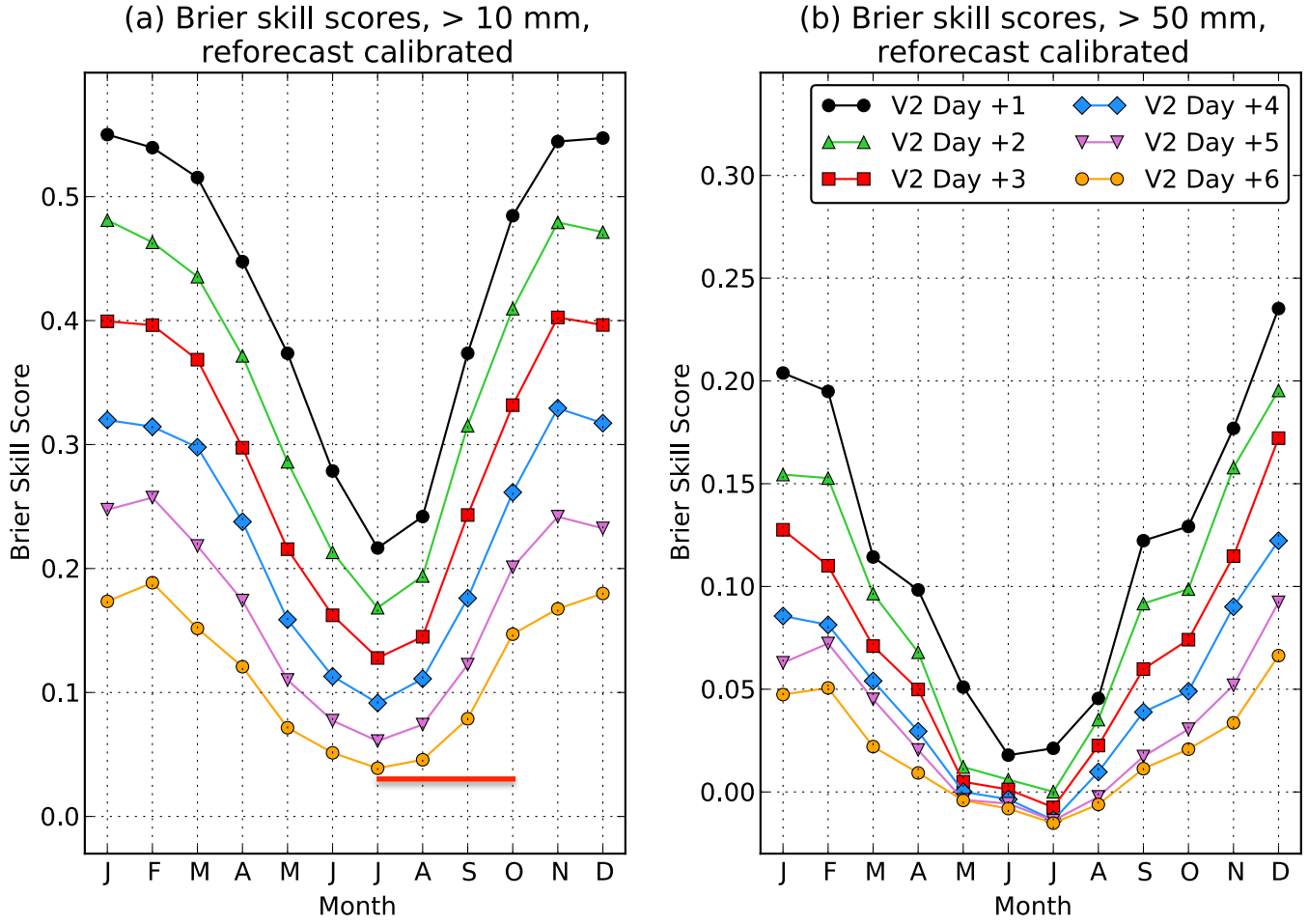


For each pair (e.g. red box), on the left are old forecasts that are somewhat similar to this day's ensemble-mean forecast. The boxed data on the right, the analyzed precipitation for the same dates as the chosen analog forecasts, can be used to statistically adjust and downscale the forecast.

Analog approaches like this may be particularly useful for hydrologic ensemble applications, where an ensemble of weather realizations is needed as inputs to a hydrologic ensemble streamflow system.

Skill of calibrated precipitation forecasts

(over US, 1985-2010, "rank analog" calibration method)



Verification here against 32-km North American Regional Reanalysis (tougher).
Verification in previous plot against 1-degree NCEP precipitation analysis (easier).